Operation and Performance of the PHENIX Experiment at RHIC

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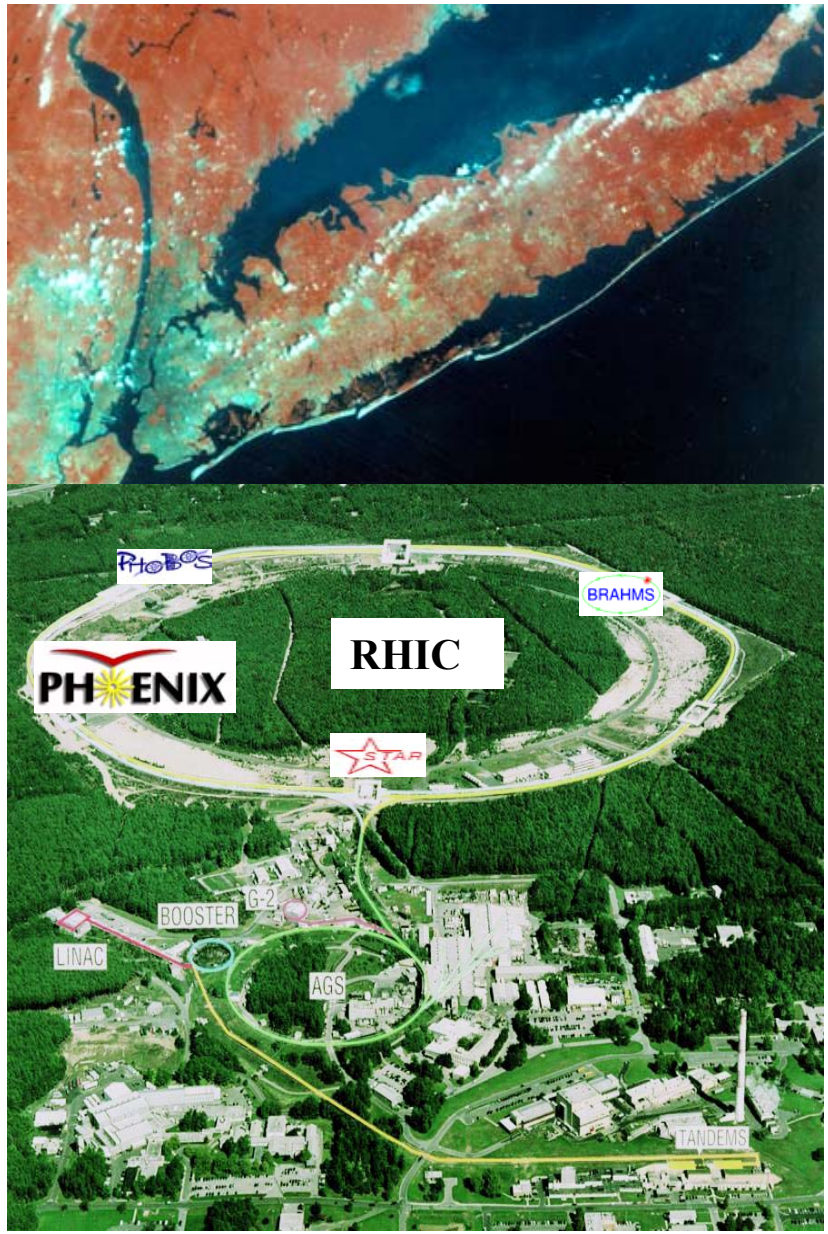
The Relativistic Heavy Ion Collider at BNL

- Two independent rings 3.83 k in circumference
  - 120 bunches/ring
  - 106 ns crossing time
- Maximum Energy
  - $s^{1/2}$ = 500 GeV p-p
  - $s^{1/2}$ = 200 GeV Au-Au per N-N collision
- Design Luminosity
  - Au-Au $2x10^{26}$ $cm^{-2}s^{-1}$
  - p - p $2x10^{32}$ $cm^{-2}s^{-1}$ (polarized)
- Capable of colliding any nuclear species on any other nuclear species



The PHENIX Collaboration

12 Countries
51 Institutions
400+ Collaborators

University of São Paulo, São Paulo, Brazil
Academia Sinica, Taipei 11529, China
China Institute of Atomic Energy (CIAE), Beijing, P. R. China
Laboratoire de Physique Corpusculaire (LPC), Universite de Clermont-Ferrand, 63170 Aubiere, Clermont-Ferrand, France
Dapnia, CEA Saclay, Bat. 703, F-91191, Gif-sur-Yvette, France
IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, BP1, F-91406, Orsay, France
LPNHE-Palaiseau, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128, Palaiseau, France
SUBATECH, Ecole des Mines at Nantes, F-44307 Nantes, France
University of Muenster, Muenster, Germany
Banaras Hindu University,Banaras, India
Bhabha Atomic Research Centre (BARC),Bombay, India
Weizmann Institute, Rehovot, Israel
Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
Hiroshima University, Higashi-Hiroshima 739, Japan
KEK, Institute for High Energy Physics,Tsukuba, Japan
Kyoto University, Kyoto, Japan
Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
RIKEN, Institute for Physical and Chemical Research, Hirosawa, Wako, Japan
University of Tokyo, Bunkyo-ku, Tokyo 113, Japan
Tokyo Institute of Technology, Ohokayama, Meguro, Tokyo, Japan
University of Tsukuba, Tsukuba, Japan
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Cyclotron Application Laboratory, KAERI, Seoul, South Korea
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Korea University, Seoul, 136-701, Korea
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Yonsei University, Seoul 120-749, KOREA
Institute of High Energy Physics (IHEP-Protvino or Serpukhov), Protovino, Russia
Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
Kurchatov Institute, Moscow, Russia
PNPI: St. Petersburg Nuclear Physics Institute, Gatchina, Leningrad, Russia
Lund University, Lund, Sweden
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Brookhaven National Laboratory (BNL), Upton, NY 11973
University of California - Riverside (UCR), Riverside, CA 92521, USA
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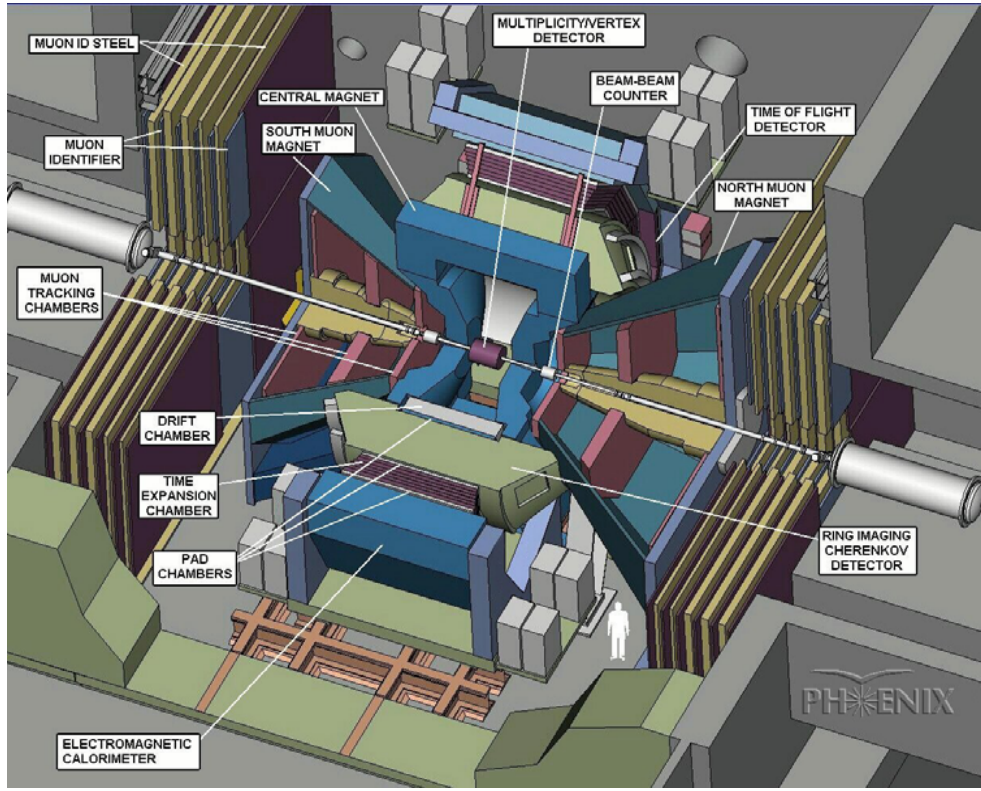
Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
LANL: Los Alamos National Laboratory, Los Alamos, NM 87545, USA
LLNL: Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
University of New Mexico, Albuquerque, New Mexico, USA
New Mexico State University, Las Cruces, New Mexico, USA
Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA

Welcome to PHENIX

Tale of the Tape:

- Begun Operation June 2000
- 12 Detector subsystems
- 4 Spectrometer arms
- Total weigh = 3000T
- 315,000 readout channels
- >125 Varieties of custom printed circuit boards
- 13 ASICs designed specifically for PHENIX
- Pipe-lined DAQ Front-end
- 500, GHz Optical Data Links



The PHENIX Experiment is designed to probe fundamental features of the strong nuclear force including:

- The detection and characterization of the Quark-Gluon Plasma
- The spin structure of the nucleons

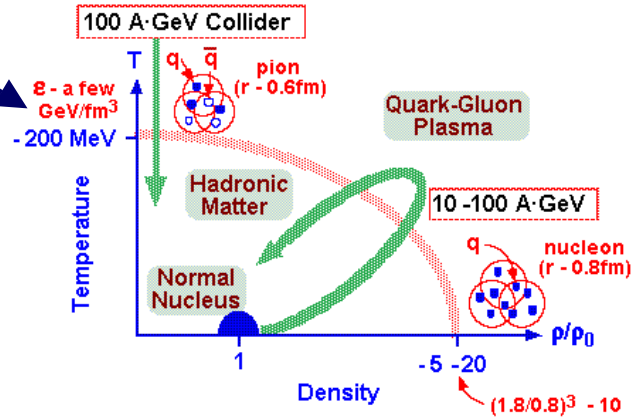
The Configuration:

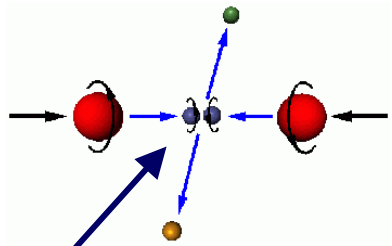
- 2 Forward Muon Arms
- 2 Central Spectrometer Arms to measure photons, electrons, and hadrons
- Event Characterizing Detectors

The Physics of PHENIX

QGP:

- Temperature and Energy Density
  - dN/dy, E_T , Single particle spectra
- Jet Quenching, Medium Effects
  - High p_T jets using leading π^0, $\pi^{\pm}$
- Space –Time Evolution
  - HBT($\pi\pi$, KK,pp), Flow
  - Event by Event Fluctuations
- Deconfinement
  - J/Ψ, Ψ'→ e+e-,μ+μ-, Υ→μμ
- Chiral Symmetry Restoration
  - φ→e+e-,K+K-, φ,ω,ρ width/shift
  - DCC's $\pi^0/\pi^{\pm}$
- Heavy Quark Production
  - K/ π , φ, J/Ψ, Ψ', Υ, D, B mesons
- Thermal Radiation
  - γ, γ*→ e+e-, μ+μ-



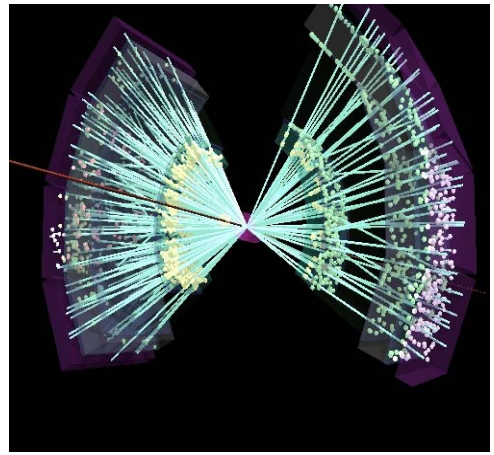


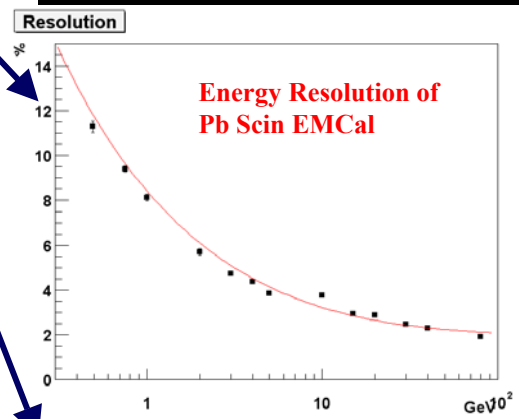
Nucleon Spin:

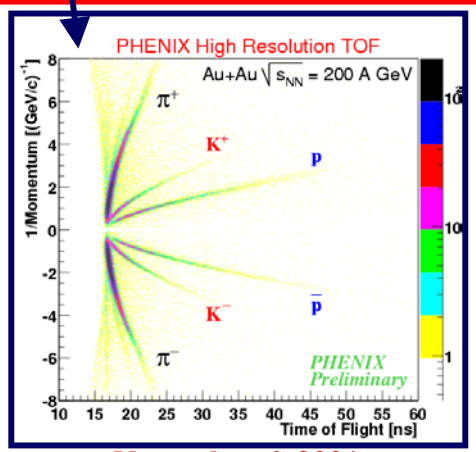
- Gluon spin: ΔG
  - Direct γ, high p_T π's
- Sea quark spin: $\Delta\bar{u}$, $\Delta\bar{d}$
  - W^+/W^- production
  - Drell-Yan Polarization

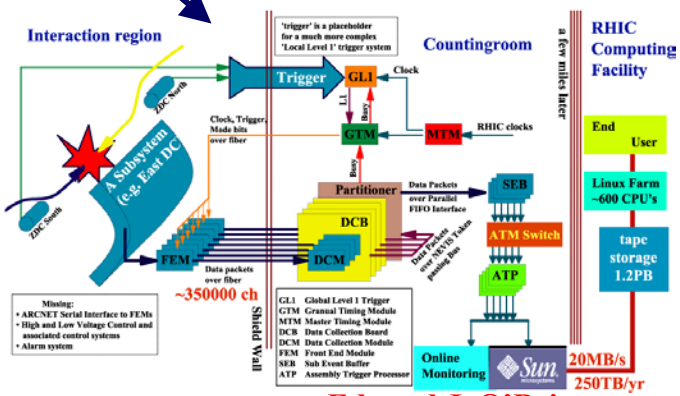
Challenges for the Detector Design

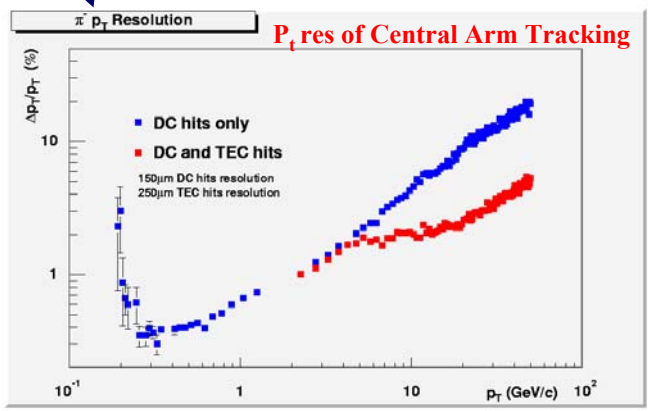
- High Particle Multiplicity/Event
  ($dN_c/dy \cong 1000$)
- Maintain performance over large dynamic range in E and pt (300 MeV – 50 GeV)
- Significant particle ID rejections
  $e/\pi = 10^{-4}$, $\mu/\pi = 10^{-4}$, $\pi/K/p = 10^{-3}$
- DAQ/Trigger operates in varying environments
  - Event rate O(10 kHz), Particle mult. O(1000/evt)
  - Event rate O(1 MHz), Particle mult. O(10/evt)





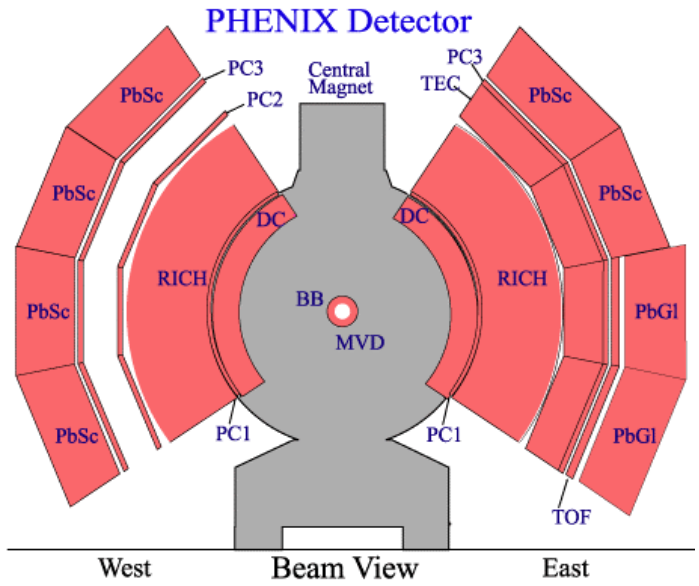






The Detector's Design Strategy

- Detector Redundancy
- Fine Granularity, Mass Resolution
- High Data Rate
- Good Particle ID
- Limited Acceptance



Charged Particle Tracking:

- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers

Particle ID:

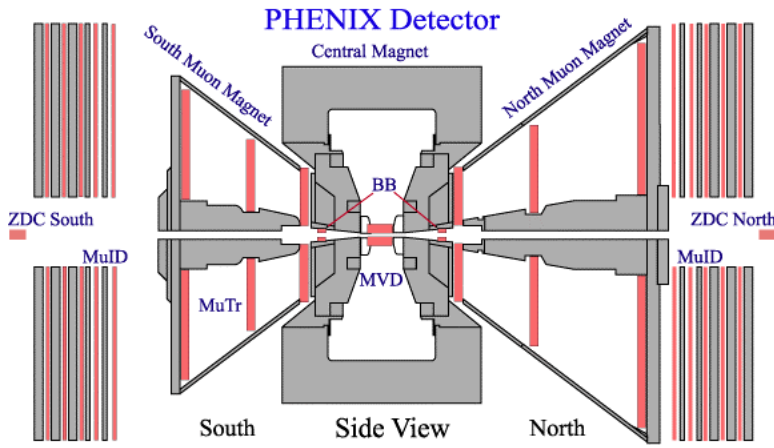
- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT's)

Calorimetry:

- Pb Scintillator
- Pb Glass

Event Characterization:

- Multiplicity Vertex Detector (Si Strip,Pad)
- Beam-Beam Counter
- Zero Degree Calorimeter

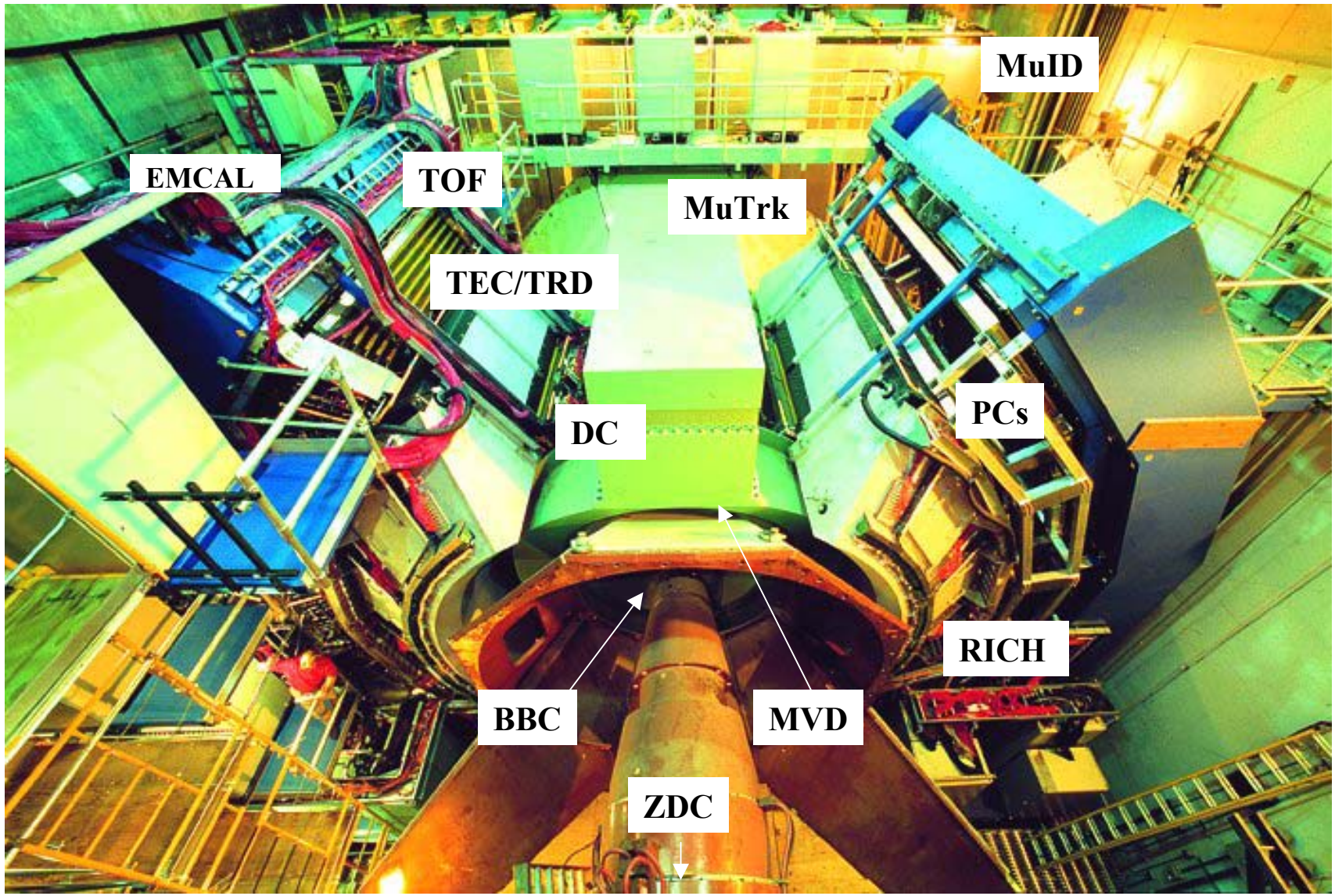


Some Unique PHENIX Technologies

- Large Area Cathode Strip Chamber with 100 μm position resolution
- Fine-segmented EMCal (0.01 Φ, 0.01 η) with $\sigma_t < 0.5$ ns
- Time Expansion Chamber that combines tracking, dE/dx and TRD
- Drift Chamber configured as focusing –jet chamber
- Ring Imaging Cerenkov Counter readout with 5000+ PMTs
- Low mass, non-projective pixel-pad wire chambers covering ~100 m^2
- Time of Flight system with $\sigma_t < 100$ ps
- Fully data-pipelined front-end electronics
- All data, timing, control and serial communication between detector and counting house is via optical link.

PHENIX

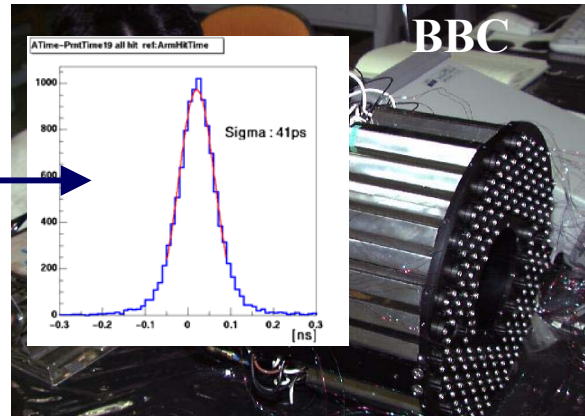
A Crowded Experimental Hall

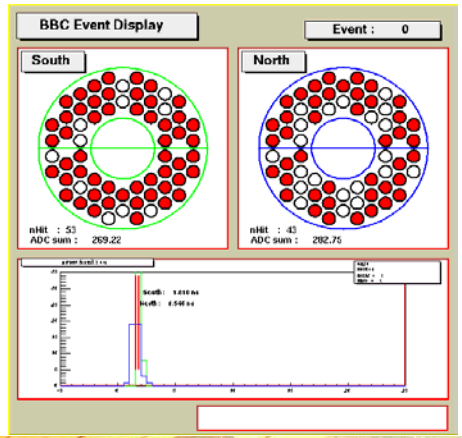


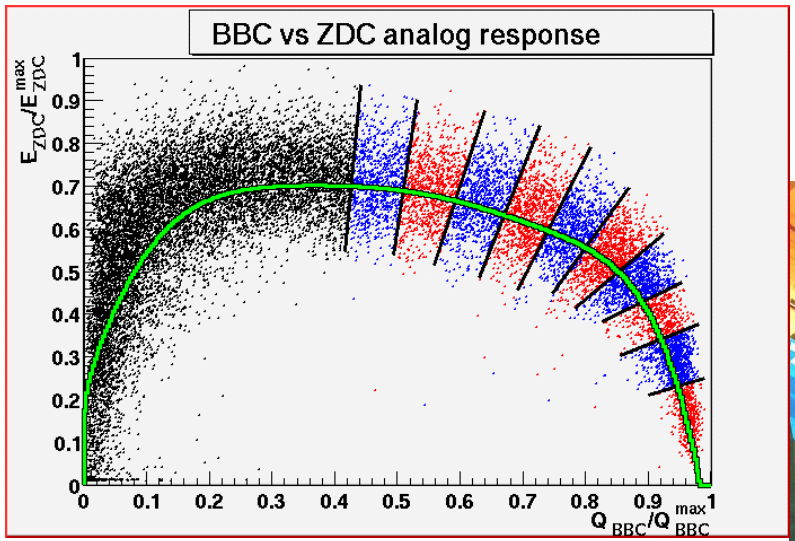
Event Characterization Detectors

Beam-Beam Counter and Zero Degree Calorimeter

- BBC is 2 arrays of 64 PMTs with quartz radiators
  - Provides T0 for PHENIX. σ_t = 50 ps
- ZDC is Cu-W calorimeter with fiber readout.
  - Common centrality measure for all 4 RHIC experiments
- Combined they provide the PHENIX LVL1 centrality trigger

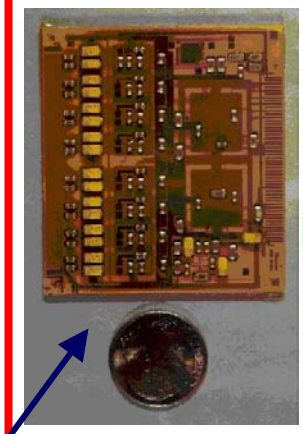


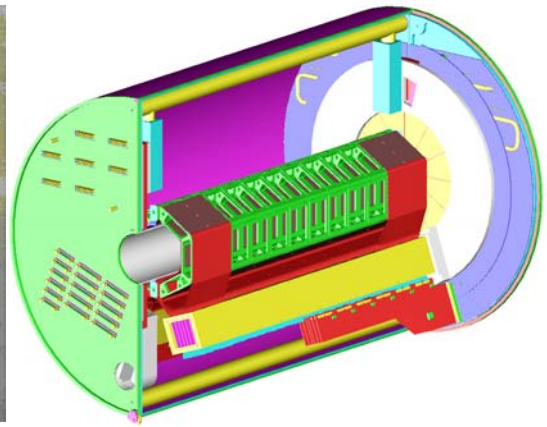


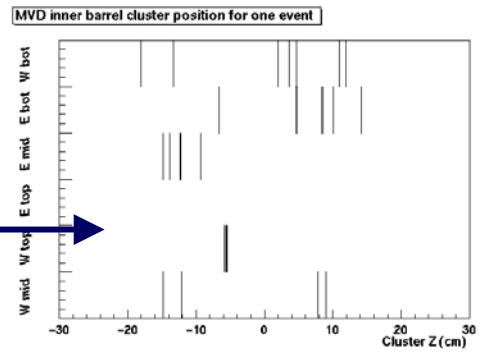


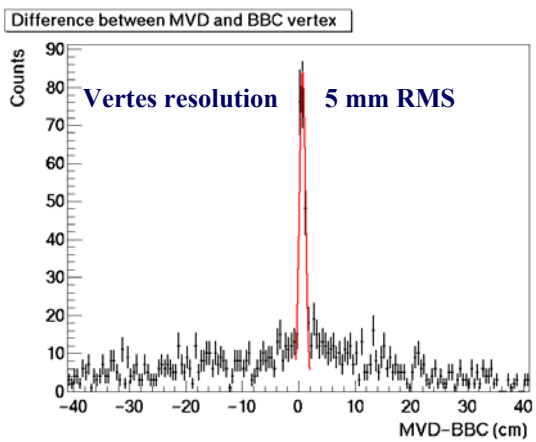
Event Characterization Detectors
Multiplicity Vertex Detector

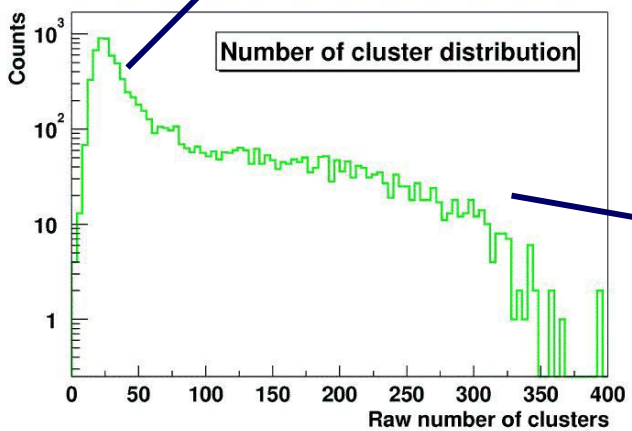
- Two concentric barrels of 300μm Si strips
- Two endplates of Si pads
- Total coverage of $-2.5 < \eta < +2.5$
- 28,672 Si strips, 6048 Si pads
- Determines event vertex and measures particle multiplicity/event
- Electronics is bare die on ceramic Multi- Chip Module

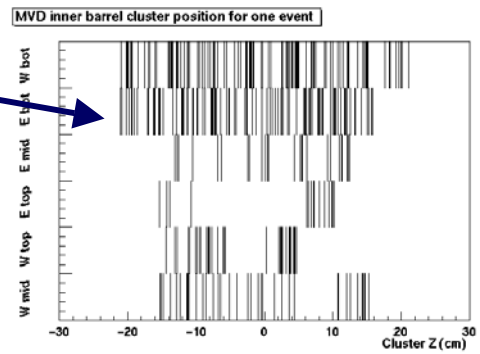






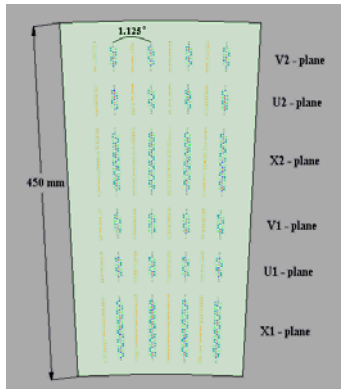


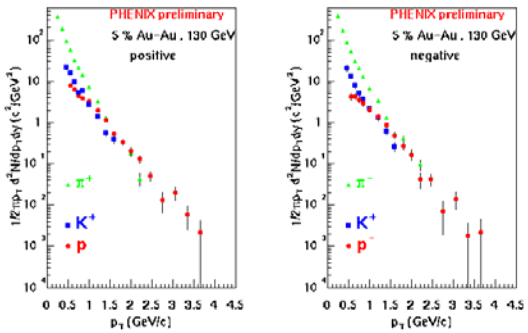




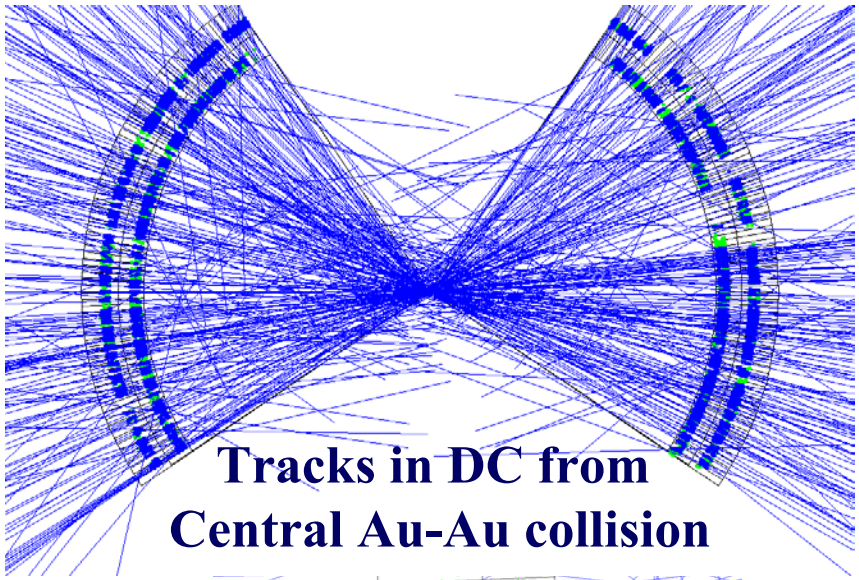
Tracking Detectors: Drift Chamber

- Jet -chamber anode/cathode structure modified for HI high multiplicity
- Joint Russia/US design & construction
- All Titanium frame
- $\sigma_x = 120\ \mu m$, two-track sep = 2mm

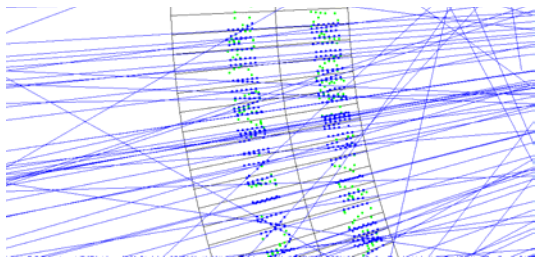




Identified particle spectra using tracking system and TOF



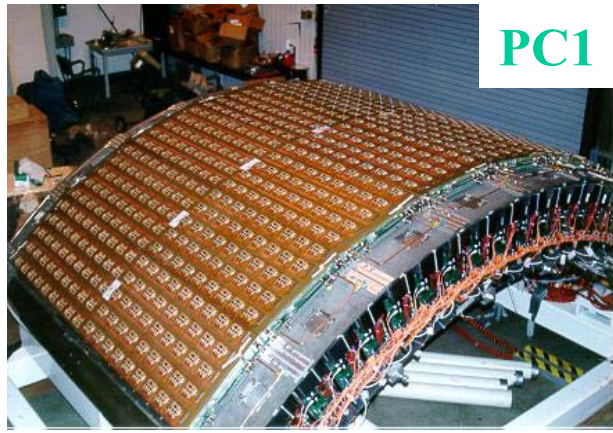
Tracks in DC from Central Au-Au collision

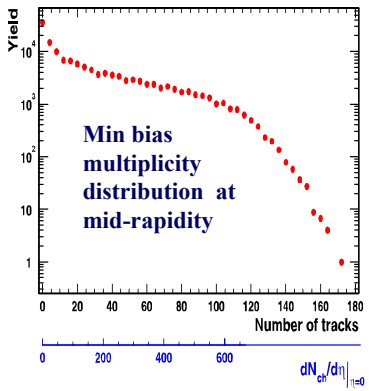


DC wires with kapton wire dividers

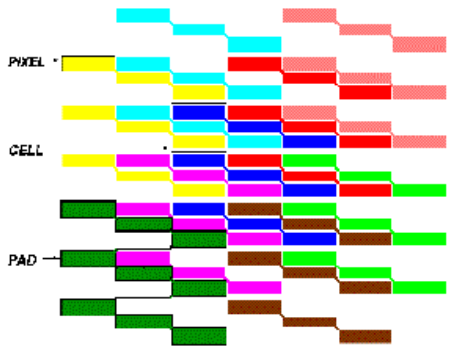
Tracking Detectors: Pad Chambers

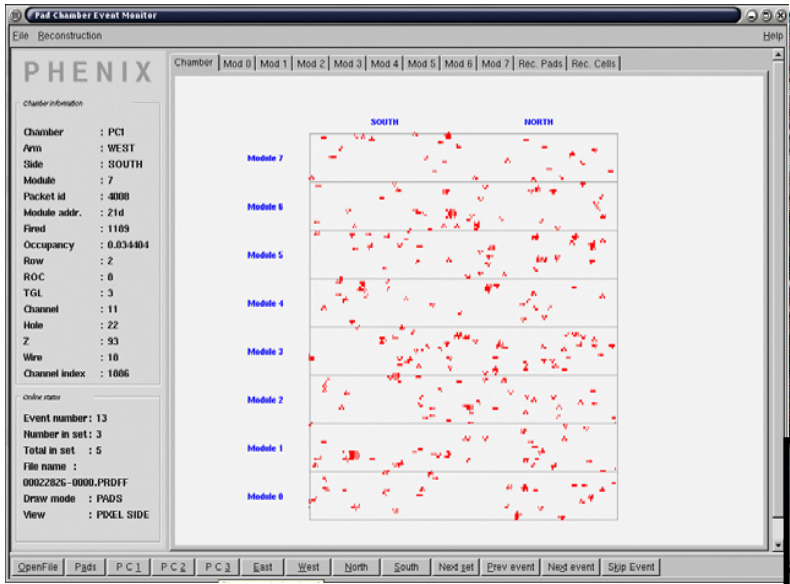
- Cathode wire chambers using fine granularity pixel pad readout
  - 2-D hit position, $\sigma_x = \sigma_y \sim O(\text{ mm})$
  - 173k channels total, ~ 100 m^2 detector coverage
- Low-mass , rigid honeycomb/circuit board construction
- All signal digitization takes place on-board in detector active region. Solves interconnect problem.





Pixel Pad Cathode Pattern

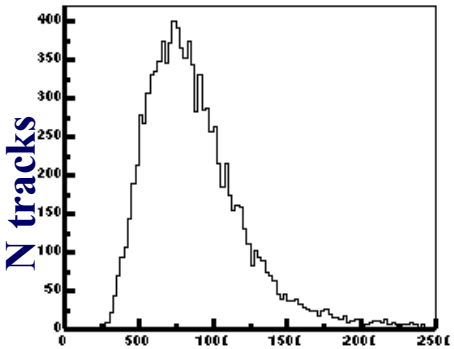




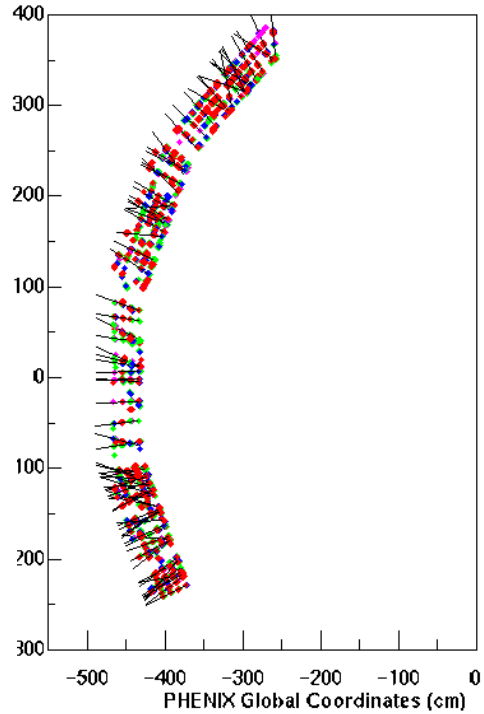
Clusters in PC from Central Au-Au collision

Tracking Detectors: Time Expansion Chamber

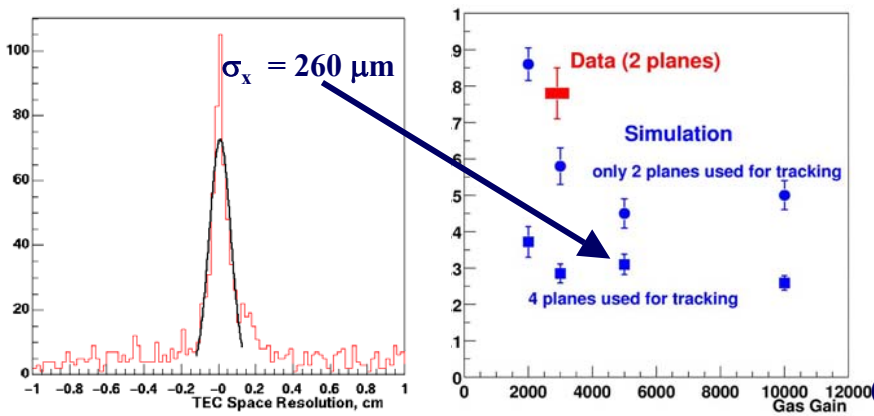
- 24 TEC Chambers arranged in 4, 6-Chamber sectors
- Used for tracking and PID (dE/dx,TR). σ_x = 260 μm
- dE/dx: e/π = 5% at 500 MeV/c (4 pls), e/π = 1.5% (6pls)
  Important for momentum resolution $p_T > 4.0$ GeV/c
- Designed for TRD Upgrade . High momentum e/π

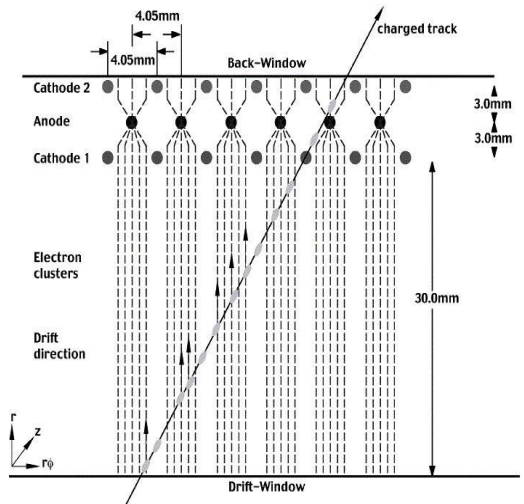


Sum FADC counts/recon. track



Tracks in TEC from Central Au-Au Collisions

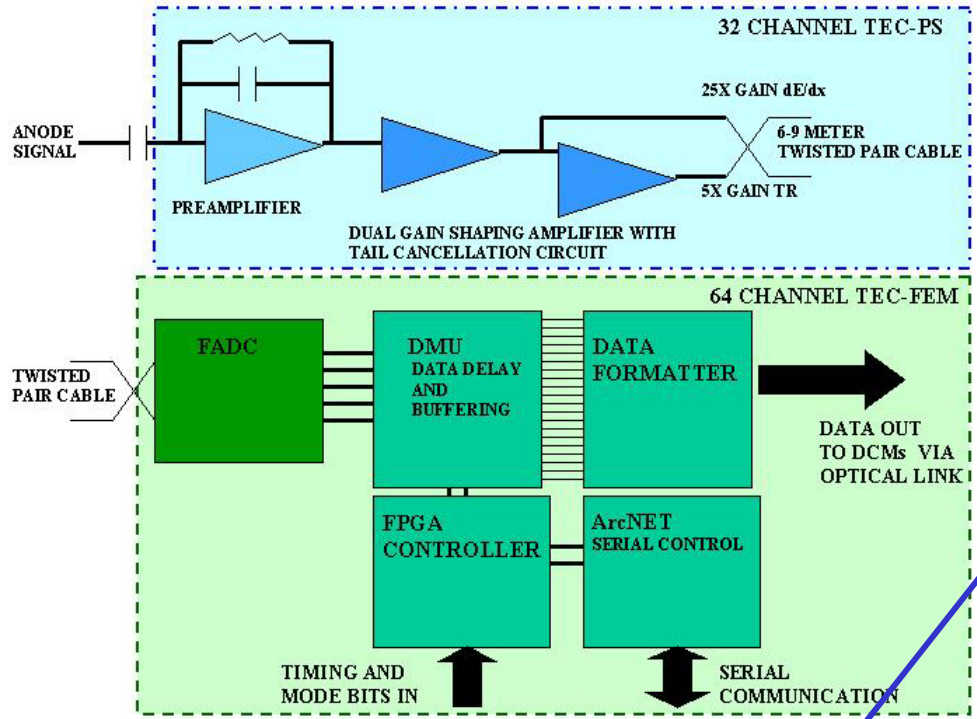


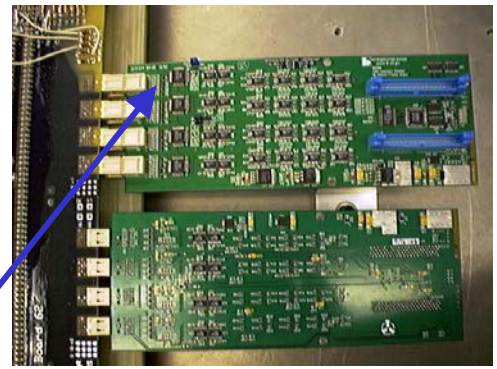


TRD Radiator

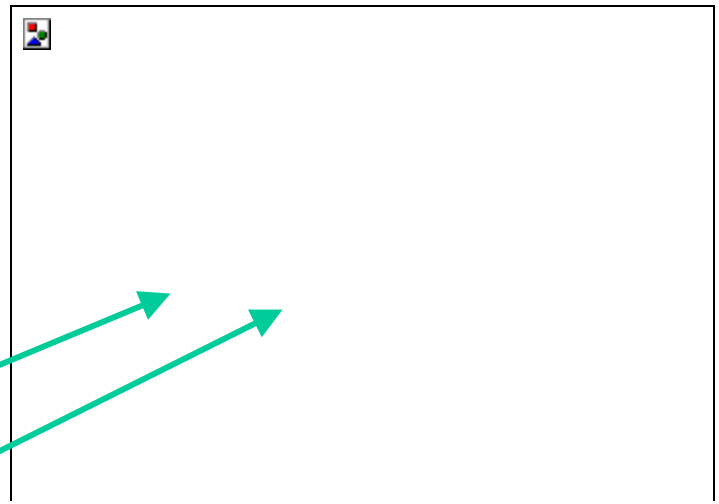
PHENIX TEC/TRD Electronics

Up to 20,500 Instrumented TEC/TRD Channels





32 channel Preamp/Shaper PCB w/ remote calibration control and ~1 fC RMS system noise



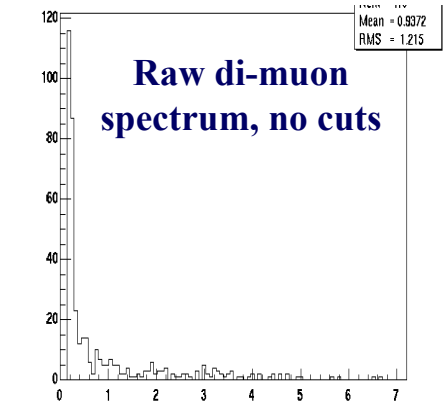
64 channel Front End Module(FEM) w/ digitizing , data formatting and optical data transmission

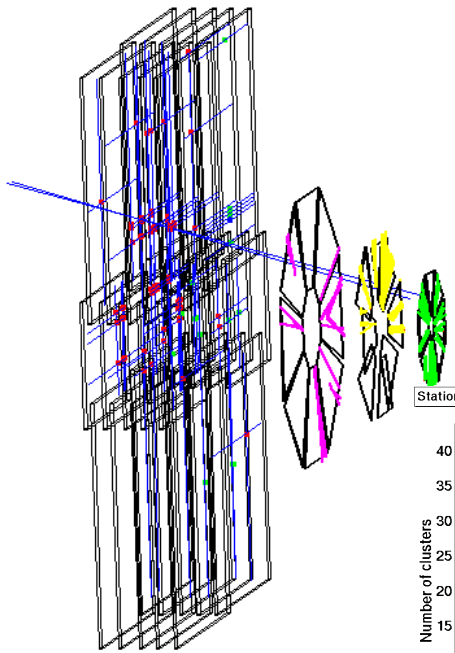
3 ASICs designed for TEC/TRD:

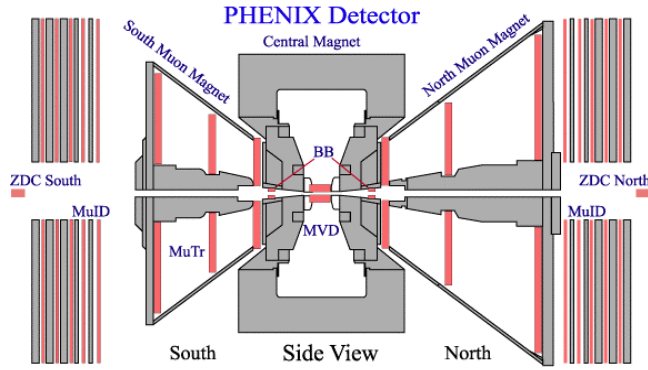
- **Octal Preamp/Shaper w/ tail cancellation and dual gain for both dE/dx and TR. Full serial control of gain, shaping time and tail cancellation.**
- **Non-linear, 40 MHz, FADC with 9-bit dynamic range, 9-bit precision and 5-bit encoding.**
- **Digital Memory Unit for data formatting with programmable delay and memory depth.**

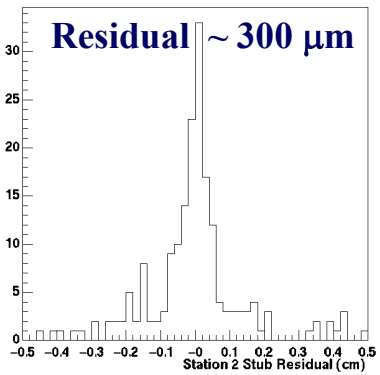
Tracking Detectors: Cathode Strip Chambers

- First cathode-strip chambers (CSC) used in an experiment
- Low mass honeycomb-printed circuit board and etched metalized-mylar design
- Each CSC station has a position resolution of σ_x=100 μm
- 20k electronics channels/spectrometer arm

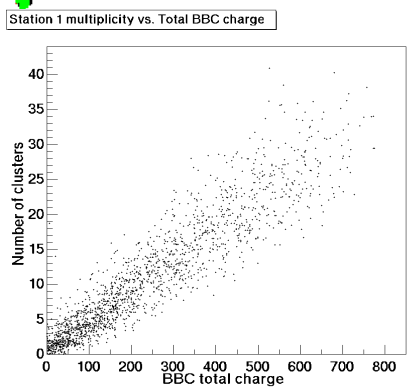






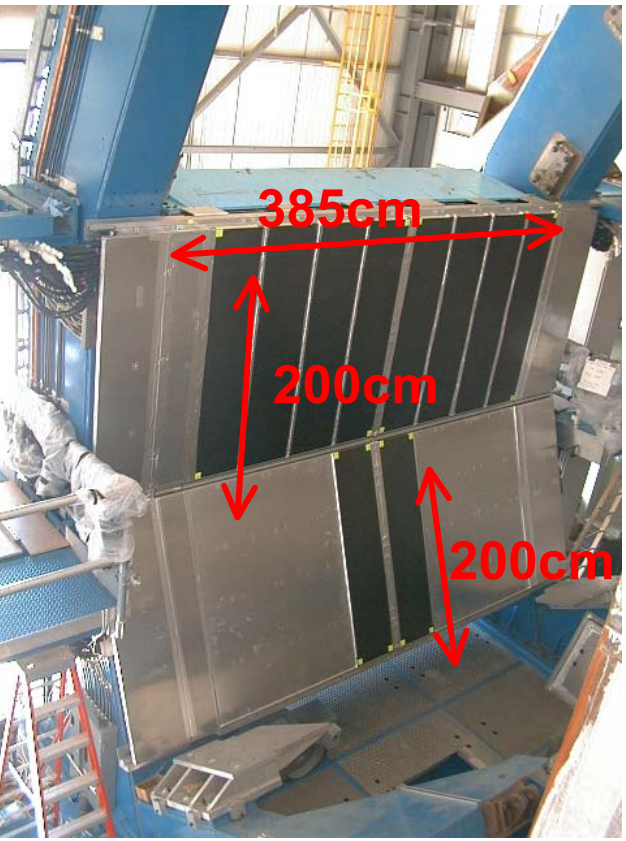


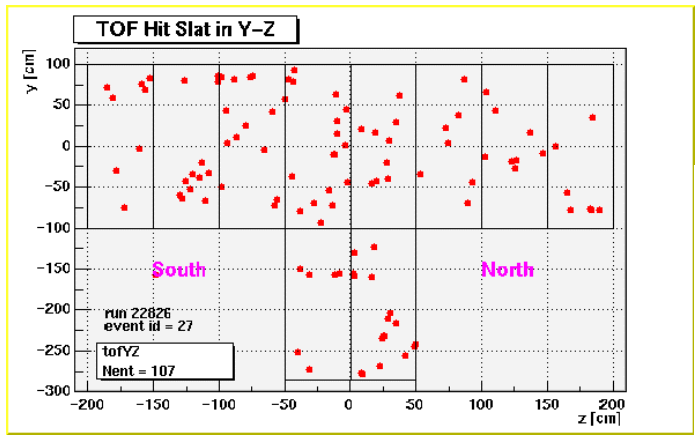
Reconstructed muon In Au-Au Collision



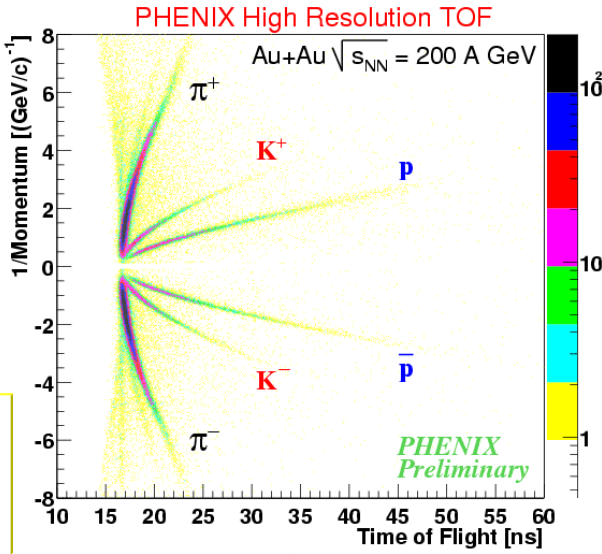
Particle ID Detectors: Time of Flight

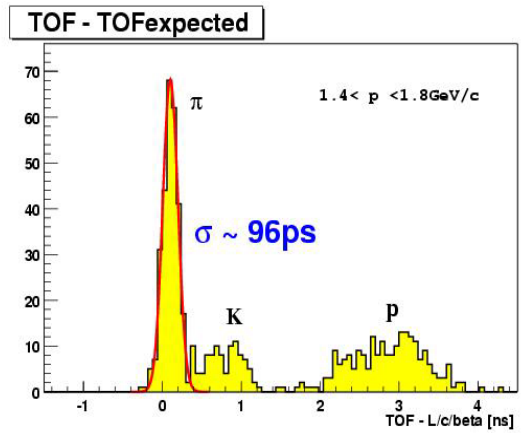
- 1000 finely segmented slats readout w/ 2000 PMTs
- Combines with BBC timing for and overall time resolution of $\sigma_{TOF} < 96$ ps
- K/π separation <~ 2 GeV/c
- p/K separation <~ 4 GeV/c

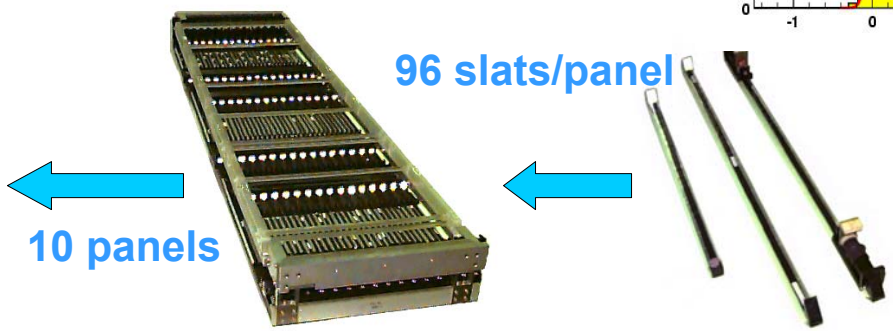




Clusters in TOF from Central Au-Au collision

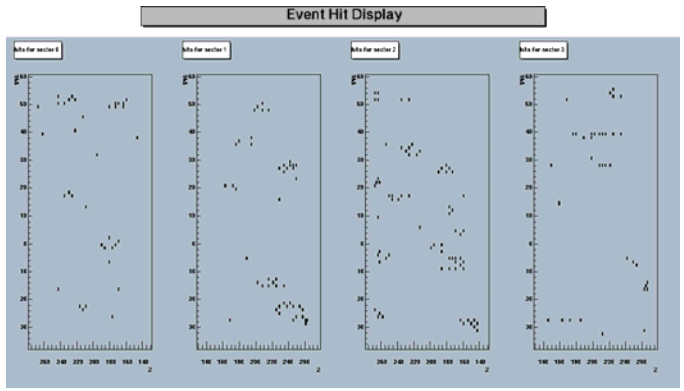




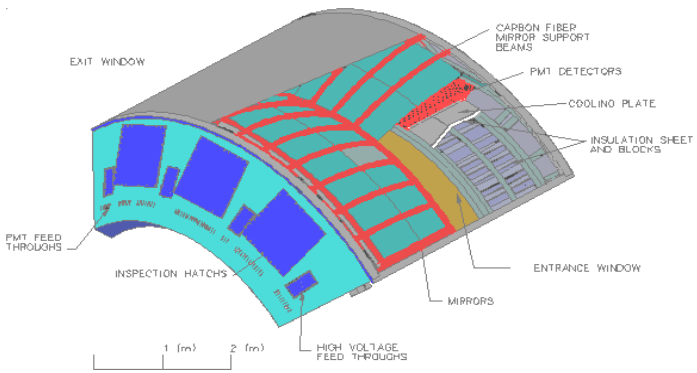


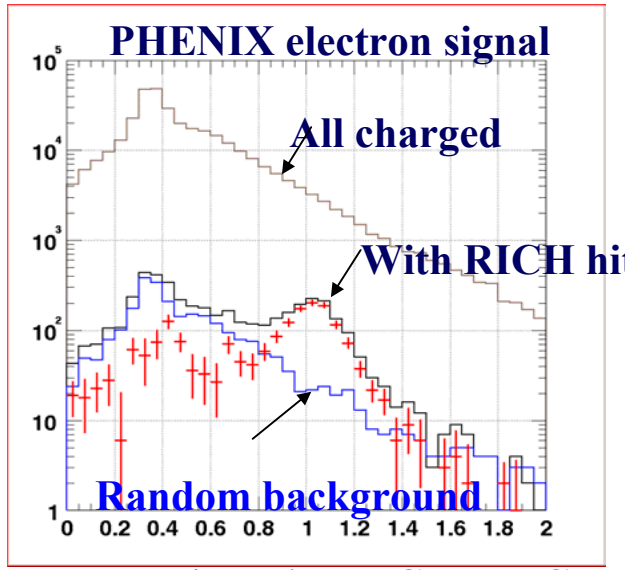
Particle ID Detectors: Ring Imaging Cerenkov Counter

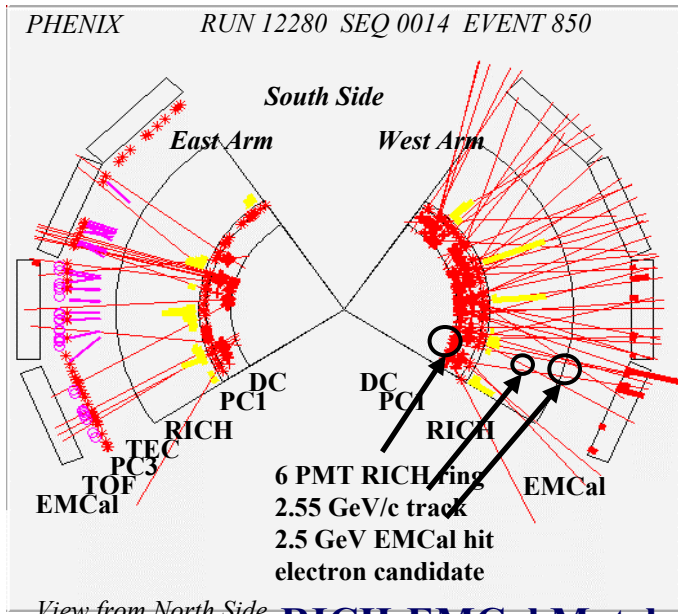
- Gas radiator CO_2 , e/π separation for p < 5 GeV/c
- 5120 PMTs sensitive to single photoelectrons, $\sigma_t < 1$ ns
- Ring resolution ~1° in both Φ and η



Rings in RICH from Central Au-Au collision



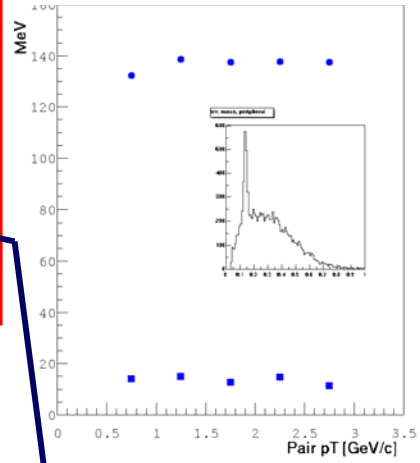




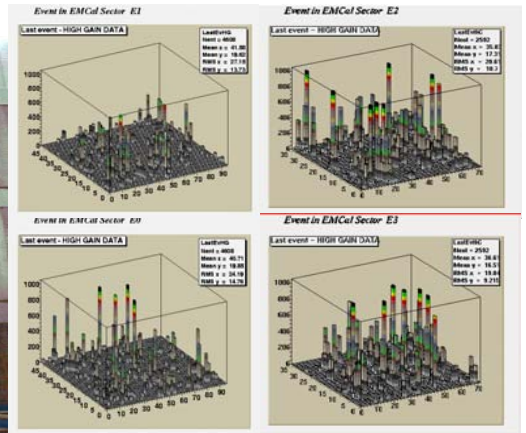
Particle ID Detectors: EM Calorimeter

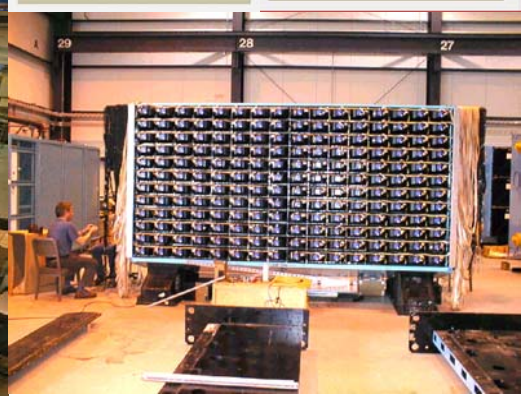
- 60 m^2 of calorimeter (6 Sectors Pb Scin, 2 Sectors PbGlass)
- Very Fine Segmentation .01 x .01 ($\Delta\Phi$ x $\Delta\eta$)
- Timing $\sigma_t \sim 400$ ps Pb Glass $\sigma_t \sim 400$ ps Pb Scin
- $\sigma_E = 8.2\%/\sqrt{E}+1.9\%$ Pb Scin, $\sigma_E = 5.8\%/\sqrt{E}+1.0\%$ Pb Glass

Mean Values and Widths of π^0 peaks

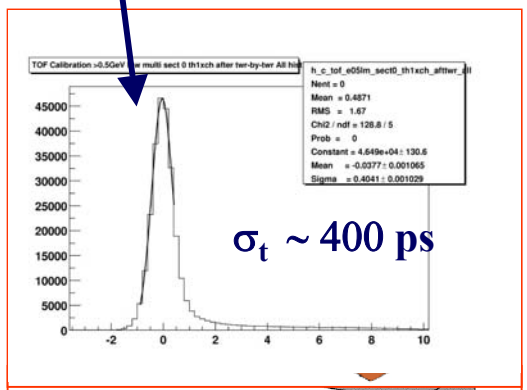


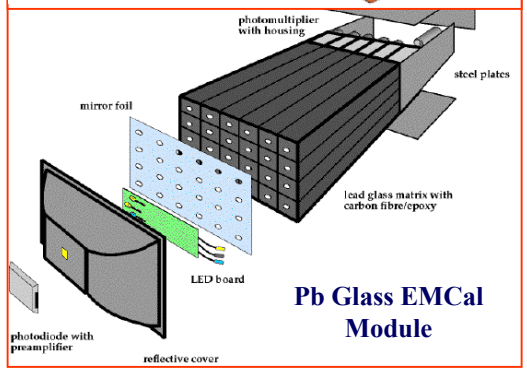
24,768 channels total, all PMTs





Clusters in EMCal from Central Au-Au Collisions

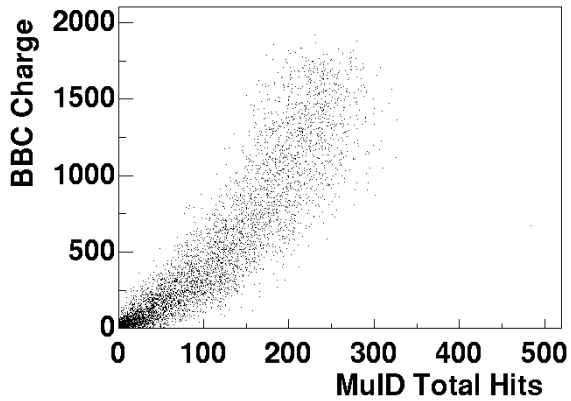


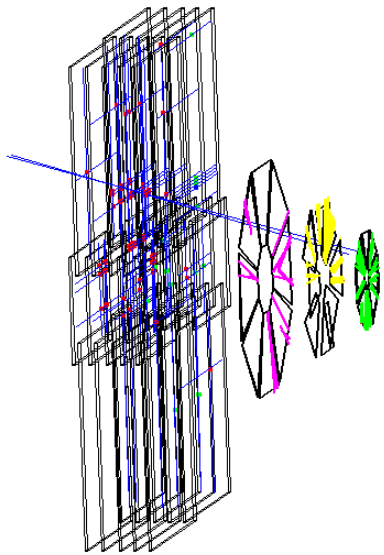


Pb Glass EMCal Module

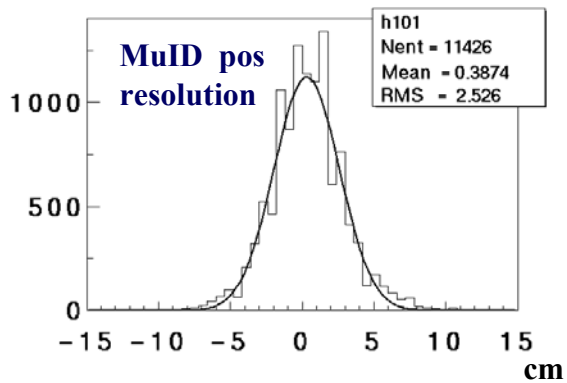
Particle ID Detectors: Muon ID

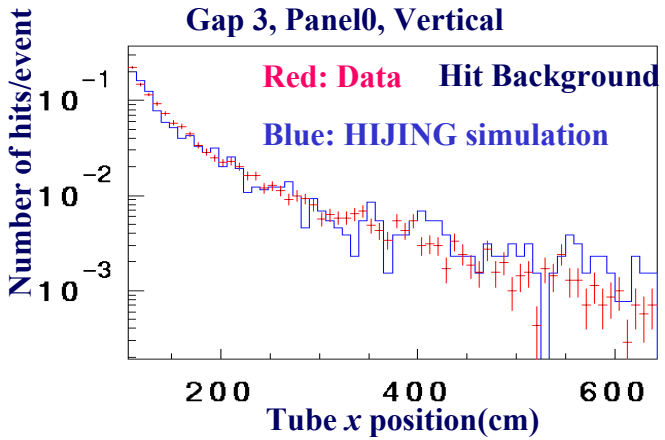
- 5 layers of steel absorber plate interleaved with 5 layers of Iarocci tubes (2x,2y 4 planes/layer)
- Active cross section of each wall 10m x 10m
- Muon low energy cutoff off 1.9 GeV/c
- Permanently sealed in place behind shield wall



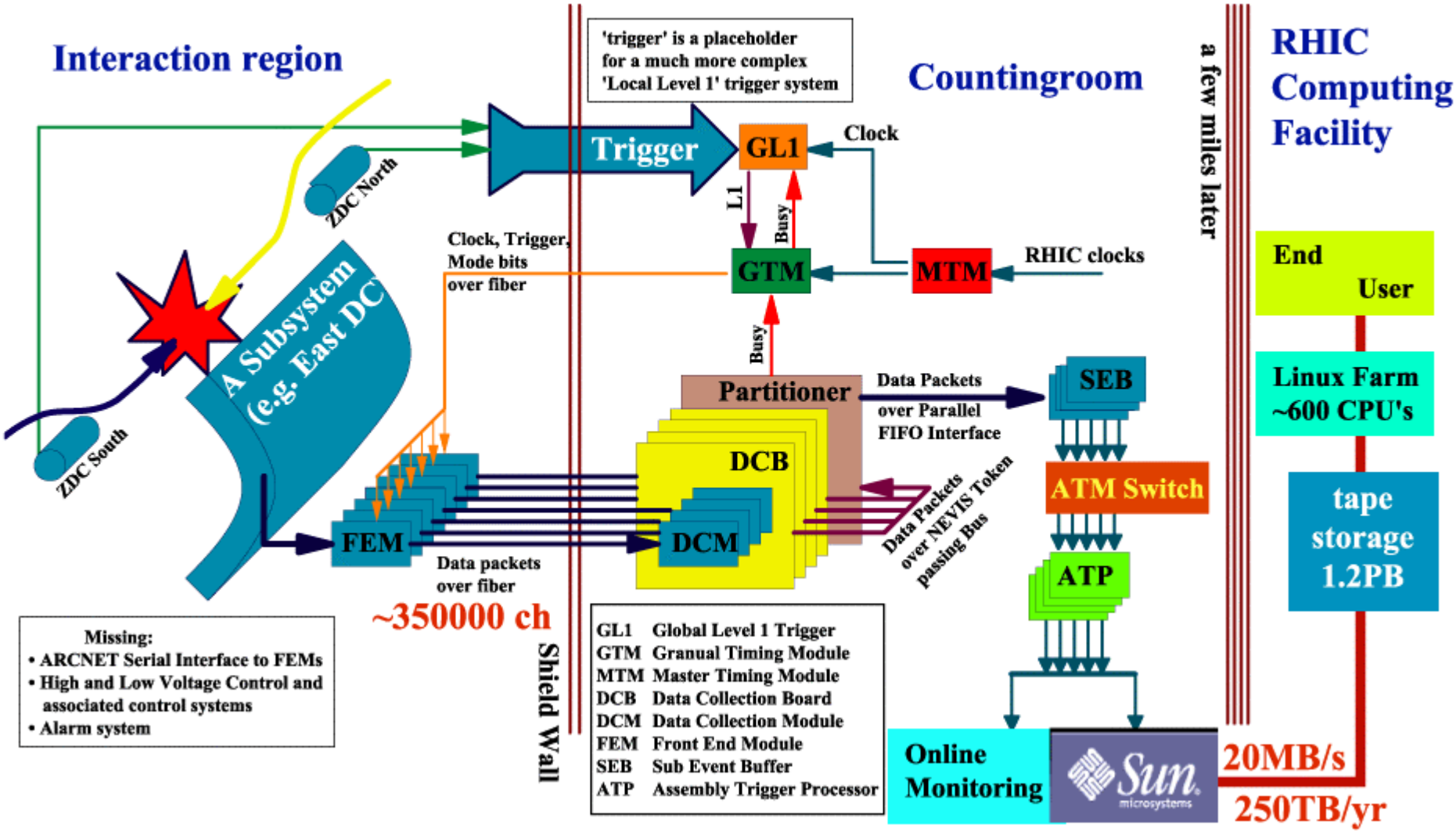


Reconstructed muon
In Au-Au Collision



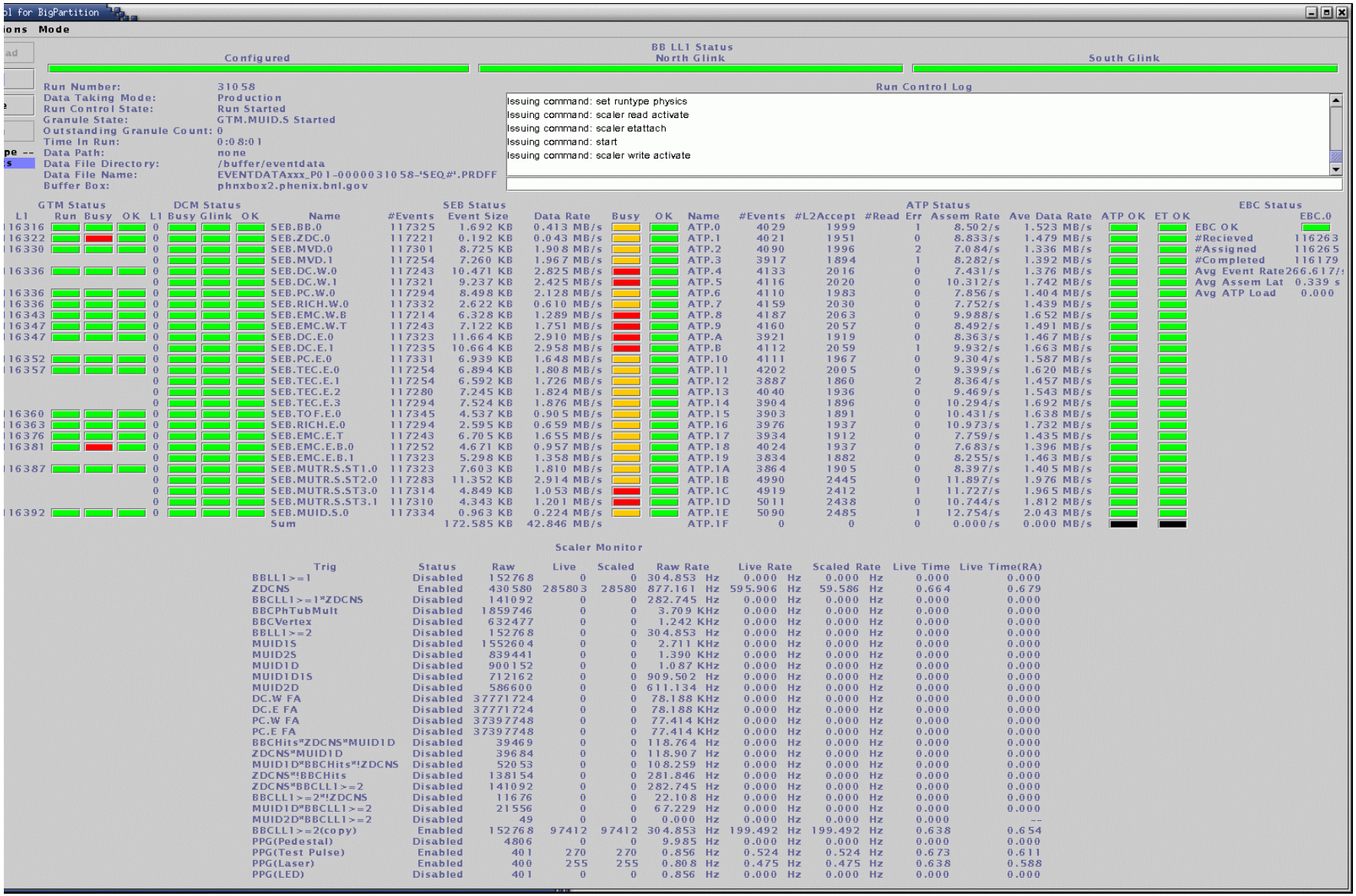


Data Acquisition System/Trigger



Data Acquisition System/Trigger

Run Control Display



Summary

First 1 ½ years of PHENIX Are a Remarkable Success

- Commissioned 12 detector subsystems
- Experiment is operating smoothly in the middle of 2nd RHIC physics run
- Implemented new high level trigger system
- First RHIC polarized p-p run starts late Nov 2001
- 3 physics papers published or submitted on 1st year results. More on the way.
- Initial results show energy densities ε, are significantly higher than predicted for a QGP phase transition. We see glimmers of very exciting physics.